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INFRARED REFLECTION

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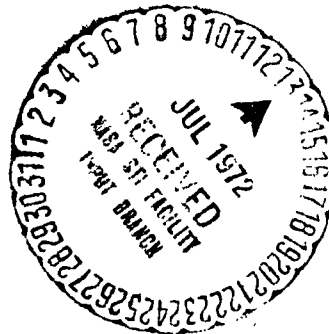
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HUMIDITY MEASUREMENT BY MEANS OF INFRARED REFLECTION

Dr. K. Hoffmann^{*}

ABSTRACT. The effect of water absorption on infrared reflection is used as a means of continuous humidity measurement. For this purpose, the intensities at a measured wavelength of 1.93 μ are compared with those of a comparison wavelength of 1.7 μ . At the wavelength 1.93 μ , there is a large amount of absorption. At the comparison wavelength 1.7 μ , there is only a small amount of absorption. The dependence of the reflection on the water content is studied using numerous spectral curves. In agreement with the theory, one finds that the optical humidity measurement is especially sensitive to small absolute humidity contents. In addition, the influences of various parameters such as particle size, variable basic absorption and layer thickness on the measurement method are discussed. The application possibilities and limitations of the method are discussed.

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Water content is decisive for many products which have technical applications. It is for this reason that methods for the accurate and convenient measurement of water content have been developed. These methods should not require contact and

* Farbwerke Hoechst AG, vormals Meister Lucius & Brüning, Frankfurt/Main-Höchst. The hundredth anniversary of the Farbwerke Hoechst AG on January 11, 1963.

** Numbers in the margin indicate pagination in the foreign text.

should operate continuously. Such methods would make it possible to determine the water content of the products during their manufacture, in particular during the liquid separation process, so that this process could be terminated at the right time.

The gravimetric method is the most often used method for determining the water content. Even though it is true that conductivity and dielectric constant measurement methods allow the continuous measurement of humidity, they impose special requirements on the characteristics of the product and presuppose a unique relationship between the humidity and the conductivity or between the humidity and the dielectric constants, respectively. These conditions are only rarely satisfied. Recently, attempts have been made to determine the water content using nuclear resonance measurements [1], which is a possibility but is quite expensive. The same is also true for more recent suggestions, such as determining the humidity using neutron scattering [2] or microwave absorption [3] (dielectric losses). Even though they have deficiencies, the conductivity method and the dielectric constant method are often used for textiles and paper, that is, products which have large areas. For example, for the conductivity method, the range within which the measurements are possible and expedient is very small and this depends greatly on the weight per area and content of conductive impurities. In the case of powdered or granular materials which are continuously being transported, it is difficult to apply the electrodes and to maintain constant degree of filling and constant packing density between the electrodes. (Reference [4] contains a summary on the various humidity measurement methods.)

Principle of the Optical Humidity Measurement Method

Over the last few years, the author and his collaborators [5, 6] have developed a method which makes it possible to directly measure the humidity of materials which are at rest or in motion without any contact and in a continuous fashion. This method is based on the fact that in the near infrared (1.93μ) water has very intensive absorption bands, which reduce the reflection in this wavelength interval to a greater or smaller degree, depending on the water content. At the same time the reflection for a comparison wavelength (1.7μ) is measured as a reference point. Water absorbs only very little at this wavelength. In this way, differences in surface structure, packing density, sensitivity of the photocell and amplifier, distance between the photometer measurement head and sample surface as well as temperature dependence of the current yield of the lead sulphide cells are eliminated. The ratio of the reflected intensities of the measurement wavelength and the comparison wavelength is formed electrically in a closed photometer amplifier. It is then displayed on an instrument or is recorded.

According to a relationship of Kubelka and Munk [7,8], the reflection depends on the function of the quotient between the absorption and scattering coefficient of the material. The scattering coefficient includes other external parameters, which essentially amounts to the particle size distribution. The eigen-absorption, on the other hand, only depends on the chemical properties of the material. The proportionality factor itself and the way it is influenced by the structure of the material is different for heavy materials, and must be determined for each case.

The water content brings about an additional absorption, especially at 1.45 and 1.93 μ . This affects the degree of reflection for the optical humidity measurement and is used in the method. Small impurities or compounds which have a very high degree of absorption in the visible range, such as coloring agents etc., possibly have no effect on the eigenabsorption at these wavelengths.

Layout of the Humidity Measurement Instrument

Figure 1 shows the optical measurement head. The light from a 15 watt bulb is decomposed into light impulses with wavelengths of 1.93 μ ⁽¹⁾ and 1.7 μ by means of a synchronous rotating filter wheel which has the correct phase. The light impulses are separated from each other by dark intervals. The wheel rotates at the line frequency. This light is deflected vertically downwards by means of a mirror and then hits the sample. The reflected light is then collected by means of a concave mirror located in the measurement head and then concentrated on a lead sulphide cell. There is an absorption filter in front of this head which rejects the visible harmonics which were let through by the interference filters. The surrounding light is practically suppressed by means of a blocking filter in front of the PbS cell. Because of the visible harmonics, the ray paths can easily be traced and the adjustment can be easily performed. | /56

The current impulses delivered by the photocell are transformed into two direct currents in a phase-dependent discriminator stage after a normal alternating current amplifier. These are

⁽¹⁾ In the case of liquid water, the absorption maximum is at 1.95 μ . In organic solvents there is a displacement towards the shorter wavelengths.

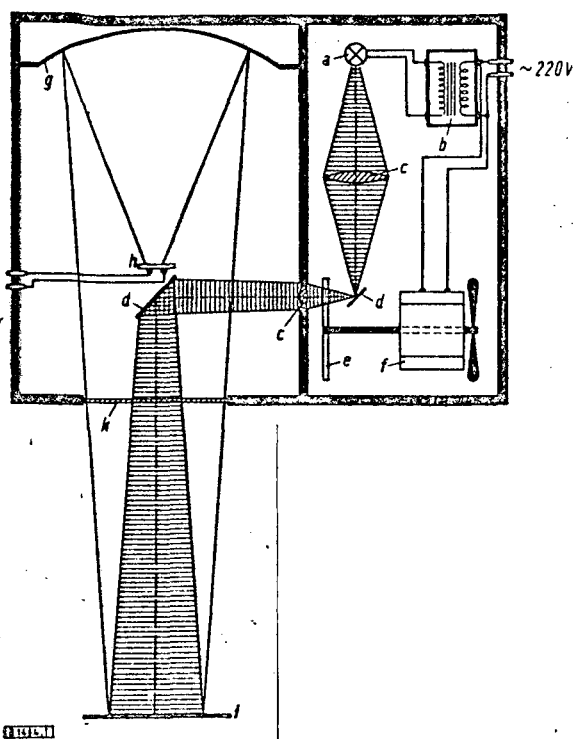


Figure 1. Measurement installation for the determination of the infrared reflection at 1.93 and 1.7 μ .

a - bulb; b - transformer;
 c - lenses; d - deflection mirror; e - filter wheel with 1.93 μ and 1.70 μ interference filters; f - synchronous motor; g - concave mirror; h - PbS photocell with blocking filter; k - covering disk.

proportional to the reflected intensities of the measured light and the comparison light. The ratio of the two direct currents is finally displayed in a quotient measurement unit. It is then recorded.

For example, conventional crossed pulse recorders or electronic compensographs can be used for this recording. Usually the latter contain control stages which are suitable for control purposes, for example, in drying installations. Because of the electrical stability, the measurement range can be made very small. The display sensitivity of crossed pulsed recorders, which result in a full scale deflection for 10% current change, can be used for very sensitive humidity displays, for example.

Recording of Spectral Curves as a Function of the Humidity Content

In order to obtain information on the relationship between the humidity and the optical reflection characteristics, it is necessary to determine reflection curves in the wavelength

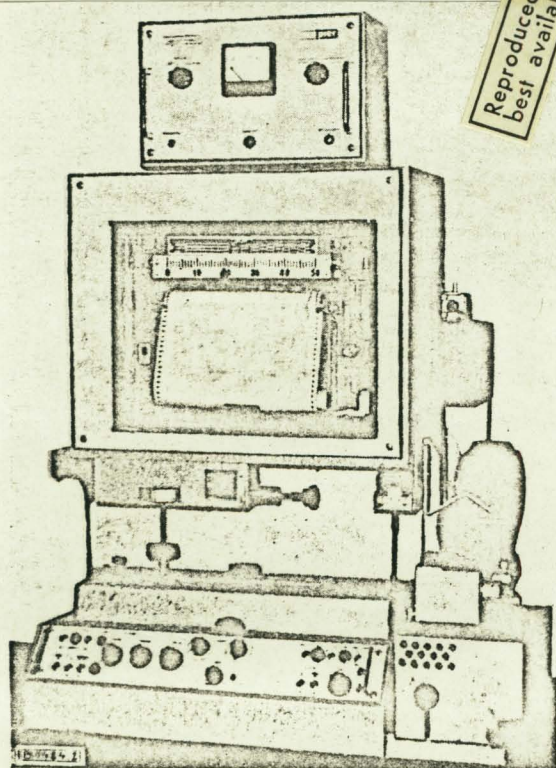


Figure 2. Recording spectral photometer.

interval between 0.7 to 2.1 μ for materials in which the humidity has been defined in various ways. We designed our own recording spectral photometer for this purpose which contains a Beckman Du monochromator and a two beam coupling. It is shown in Figure 2.

The rays are divided by means of synchronous rotating mirrors with the correct phase. The light impulses of the measurement ray input and the comparison ray input, which are separated in time, follow on the photocell. The electrical impulses produced there are amplified and are transformed into two direct currents proportional to the impulses by means of a discriminator stage. The quotient is displayed in an electronic compensograph. This method has the required stability as a function of time. This is necessary because the measurements extend over long time intervals during which neither the zero point nor the 100% line of the apparatus can change in a noticeable way.

The substances are placed into small measurement cuvettes in the 45° attachment. They consist of PVC small frames with glass covering plates which have been glued on. The 45° attachment shown in Figure 3 contains a mirror which deflects the measurement ray path and the comparison ray path by 45° from the

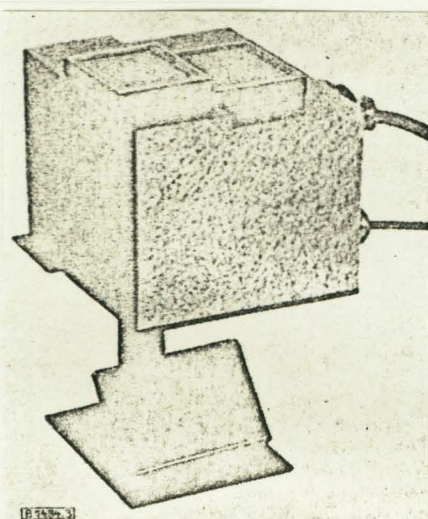


Figure 3. 45° reflection attachment with powder cuvettes.

sample housing vertically upward and then to the aperture for the measurement ray path and the comparison ray path. There is a 20 x 20 mm Infratron-PbS cell diagonally below the sample opening. It is arranged in such a way that only light which arrives at an angle of 45° can reach the cell.

The 45° attachment has the following advantage over an Ulbricht sphere for diffuse light. The eigenreflection of

the glass covering disks of the measurement cuvettes does not have any effect. In addition the zero point can be controlled in a simple way by interrupting the measurement ray path. The spectral bandwidth for the measurements is between 1 and 2 μ and below 30 $\mu\mu$ and is narrow enough to resolve the details of the reflection curves with sufficient accuracy. Because of the reduced light intensity during reflection measurements, a certain noise background component cannot be avoided, and which can be observed in the spectral curves in the form of recorder chatter.

Reflection Standard for the Near Infrared

The conventional white standards, magnesium oxide, magnesium carbonate or barium sulphate, are not suitable for exact investigations in the region of the water absorption bands. This is because they absorb more or less water and therefore have a very reduced reflection, which is not even constant. On the other

hand, Hostaflon TF powder has reflection properties which are quite constant and amount to almost 100%. It is a superior reference standard, because it does not contain any CH bonds, which absorb in the near infrared and in addition are not hygroscopic. The reflection magnitude deviates somewhat for each powder filling. We used a powder having an absolute reflection above 95%.

As a comparison, Figure 4 shows the reflection curves of Hostaflon TF and those of conventional white standards. It can be seen that only by using Hostaflon TF can one obtain unambiguous and exact reflection curves.

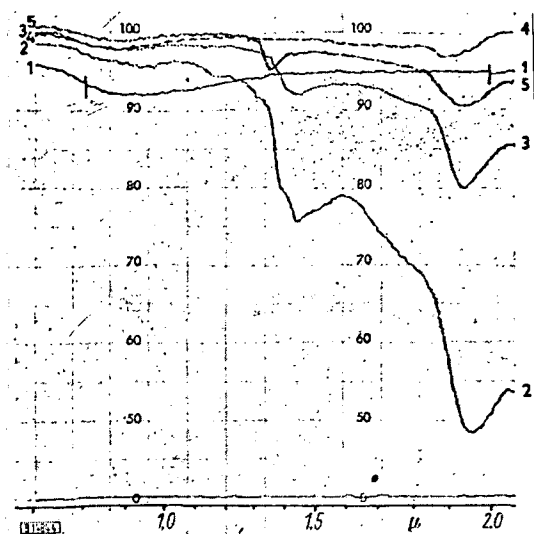


Figure 4. Reflection curves of Hostaflon TF Standard (curve 1), magnesium carbonate (curve 2), barium sulfate (curve 3), Hostaflon TF powder (curve 4) and magnesium oxide powder (curve 5).

Sample Preparation

Reproducible results can only be obtained with perfect samples which have been uniformly moistened. The simplest conditions prevail if larger amounts of the sample are available which have been uniformly moistened. The water content can then be determined gravimetrically. The following procedure has been found to be suitable for smaller sample amounts from 1 to 3 g:

The samples were filled into the PVC frames and then dried in the drying room at 120° C for several hours. Then they were weighed and left in an

evacuated exsiccator for several hours, the floor of which was covered with water. Afterwards, the absorbed water is vaporized again in several steps.

First the humidity of these samples is determined gravimetrically and then the spectral reflection is measured. One then obtains a collection of calibration curves, the so-called humidity curves, which is a family of curves which give the relationship between the water content and the infrared reflection.

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The accuracy of this measurement methods depends on the weighing accuracy and the uniformness of the humidity distribution. For example, it is possible that the photometer and the scale will measure parts of the sample which have different amounts of moisture. This can happen because during drying, the moisture can only leave through the surface. During the optical measurement a degree of moisture which is too large can be indicated through the glass plate at the base of the cuvette. The opposite is true when the humidity curve is recorded with the dry material. Since the humidity curves of both methods agree satisfactorily, it can be assumed that the moisture exchange in the layer or in the samples occurs relatively rapidly and that the rate of diffusion of the water through the surface of the measurement cuvette determines the velocity.

Discussion of the Spectral Curves

Figure 5 shows the extinction curve of pure water between 1 and 2.5 μ . Here the ranges at 1.45, 1.7 and 1.95 μ with extinctions at 12.5, 2.5 and 50 cm^{-1} are of particular interest. At 1.7 μ the water only absorbs slightly. On the other hand, all organic materials have absorption bands here, which are based on CH harmonics. Therefore this wavelength is especially

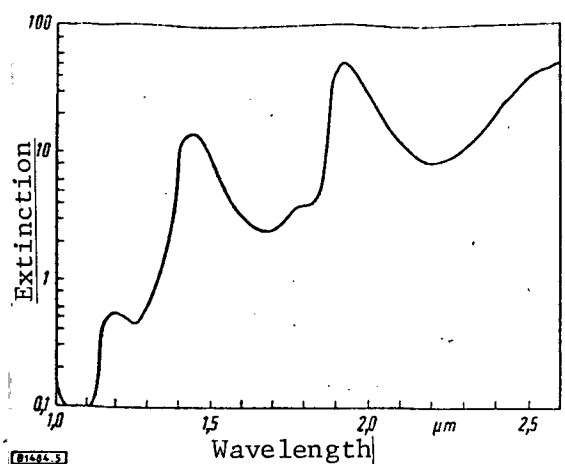


Figure 5. Extinction curve of pure water between 1 and 2.5 μ .

Water of Crystallization

In the samples, water cannot only be physically absorbed but also be chemically bound in the form of water of crystallization. Essentially two types of reflection structures are obtained. Either the water bands are very sharply defined or the curves have only a few and wide water bands. Figure 6 shows examples for both types between which transitions are possible. It can be seen that the sharpness and the formation of the OH oscillation can be influenced to a varying degree by means of intermolecular fields within the crystal grid.

Principal Types of Humidity Spectral Curves

The humidity influences the reflection in different ways for different materials. However, there is a certain order which makes it possible to establish three groups.

In the case of type 1, the water bands are located at approximately the same wavelength as for liquid water and have

well-suited as a comparison wavelength. Changes in the surface structure, packing density, etc. have the same effect on the measurement wavelength and the comparison wavelength and therefore average out when the quotient of the reflections at 1.93 and 1.7 μ is formed.

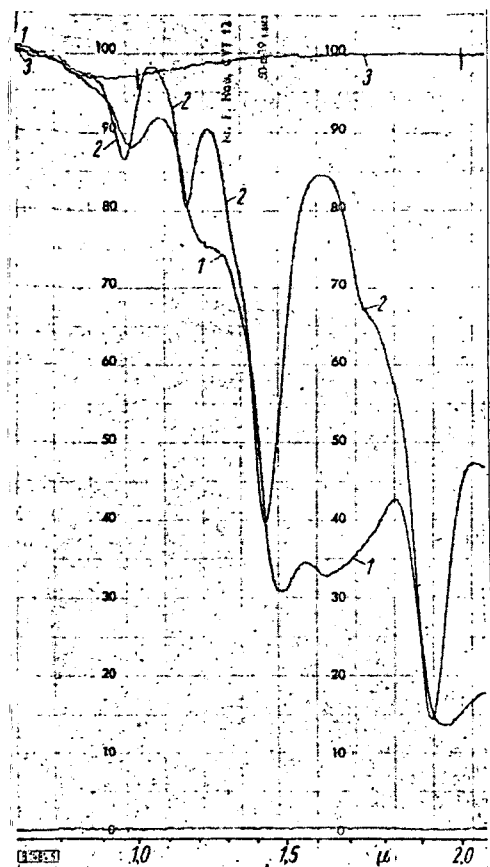


Figure 6. Reflection curves of $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ (curve 1) and $\text{Mg}(\text{ClO}_4)_2 \cdot 6\text{H}_2\text{O}$ (curve 2) compared with the comparison standard Hostaflon TF (curve 3).

boundary areas between the individual granules in this case, which then reduces the internal scattering. Hostapon T, color powder are examples of this (see Figure 8).

In the case of type 3, on the other hand, the absorption at the minimum of water extinction for 1.7μ is considerably greater than for the other two types. The reflection curves drop already

about the same extinction. An example of this (wool) is shown in Figure 7. In this case, the reflection at 1.7μ only decreases at very high water content (about 20%). For even higher water contents, the reflection curves then drop over the entire wavelength interval because the total back scattering is prevented by capillary condensation in the cavities of the product.

Type 2 essentially has the same characteristics as type 1, only the reflection values generally drop already at moderate amounts of water content. Primarily powder substances behave like this because they do not have any distinct hydrophilic character. We can also assume a type of capillary condensation in the

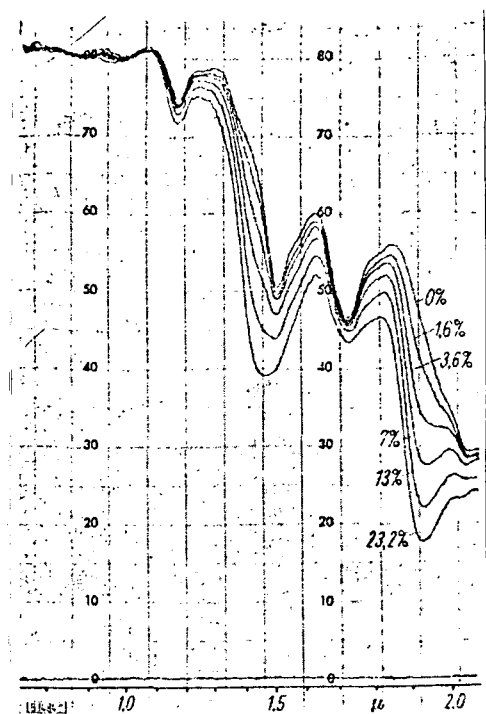


Figure 7. Reflection curve for wool for various humidity contents.

at very low humidity contents in this range. There is no plateau in this case. The absorption at 1.45μ is less pronounced and is not as much influenced as in the first two cases. Also the reflection curves decrease only at higher water content values. This behavior is characteristic for cellulose, starch and therefore also for a large number of technical products such as cotton (Figure 9), paper and similar materials. Therefore this is generally true for materials which have a more or less developed hydrophilic character.]

One can therefore come to the conclusion that the relative intensities of the water bands depend on the type of the products. This is quite plausible because the absorption spectrum of the water depends greatly on the bond state, the water connections and other influences. It can also be displaced considerably.

Table 1 shows the relative absorption intensities of the water bands at 1.7 and 1.4μ compared with those at 1.93μ which were calculated from the reflection spectra using the Kubelka-Munk relationship to be described in the following section. It can be seen that primarily the values for 1.45 and 1.7μ can vary with those for 1.93μ almost at a ratio of 1:2.

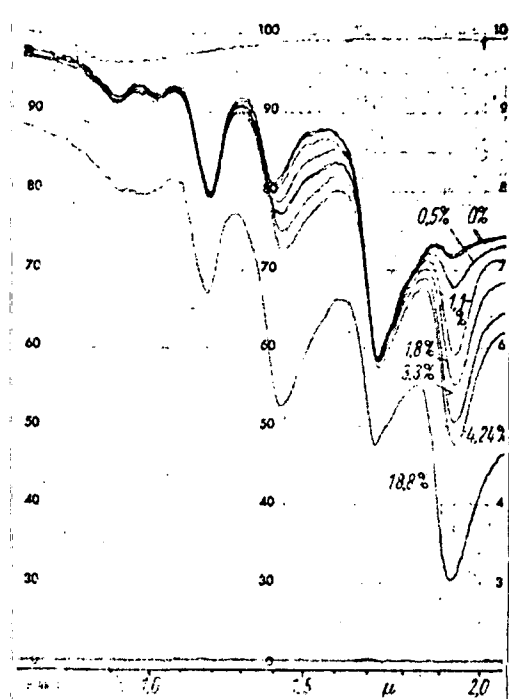


Figure 8. Reflection curve for Hostapon T for various humidity contents.

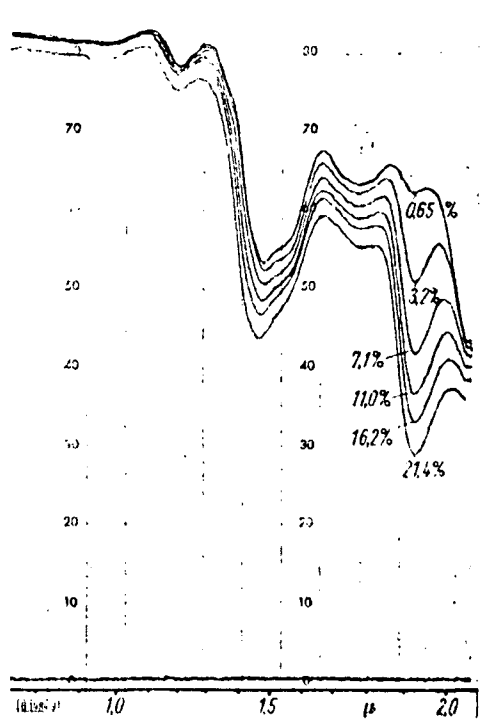


Figure 9. Reflection for cotton for various humidity contents.

TABLE 1. EXTINCTION OF WATER IN VARIOUS SAMPLES AT 1.45 AND 1.7 μ CALCULATED FROM SPECTRAL REFLECTION CURVES ACCORDING TO THE KUBELKA-MUNK RELATIONSHIP. (The extinction at 1.93 μ was set = 50 cm^{-1}).

Sample	1.45 μ	1.7 μ
Wool	12.3 cm^{-1}	1.4 cm^{-1}
Hostapon T powder	7.3 cm^{-1}	1.6 cm^{-1}
Cotton	7.1 cm^{-1}	3.6 cm^{-1}
Paper	7.1 cm^{-1}	3.0 cm^{-1}
Starch powder	7.1 cm^{-1}	3.6 cm^{-1}
Liquid water	12.5 cm^{-1}	2.5 cm^{-1}

Therefore it follows that a good accuracy is only achieved in a range from 0 to 30% humidity for type 1 and type 3 measurements and only up to about 10% humidity for type 2 measurements. However, small water contents can be measured with a good measurement accuracy in all cases.

Kubelka-Munk Theory

The relationship between the reflection and absorption is considerably more complicated than the relationship between transmission and absorption, which follows the Lambert-Beer law.

In the back scattering process, the scattering properties of the product play an important role in addition to the absorption. The higher the scattering capacity of a product and therefore the amount of back scattered light, the smaller will be the penetration depth of the light into the sample. The influence of light-absorbing components in the sample will then be correspondingly smaller.

These relationships were treated in detail by Kubelka and Munk [7, 8]]. According to them, the back scattering for infinitely thick layers and therefore the brightness of the sample can be described by means of a function containing two factors (K, the absorption and S, the scattering capacity). Both quantities appear together in the form of a quotient K/S in Equations (1) and (2), which means that only this quotient has an effect on the optical properties of the products. The reflection R_{∞} for an infinitely thick layer is

$$R_{\infty} = 1 + \frac{K}{S} - \sqrt{\frac{K^2}{S^2} + \frac{2K}{S}} \quad (1)$$

There are many formulas derived from this theory for all special cases, such as finite layer thicknesses and variable background brightness. We would like to refer to the book by Judd [9] as well as the original papers of Kubelka and Munk [7, 8].

The two component theory of Kubelka and Munk has been found to be extremely productive and today represents the foundation for the treatment of optical relationships in reflection investigations and coloring processes. It can primarily be applied to scattering by particles, which are embedded in the same medium in which the observations are taking place. In our case this is the error. All scattering process in textiles, paper, powder, etc. belong to this category. In order to apply the special equations derived by Kubelka and Munk, it is necessary to know the individual values of S and K, which are contained in R_∞ in quotient form. For this at least two independent measurements are required, for example of the reflection and layer thickness or the reflection of a layer having the same thickness on a white or black background. Other possibilities include measurement of the changes in the reflection when the absorption is increased by a certain amount. This can also be done if the absolute absorption of the material is known.

The relationships are collected in Equation (2) to (5). After introducing the abbreviations

$$a = \frac{1}{2} \left(\frac{1}{R_\infty} + R_\infty \right) \Big|$$

and

$$b = \frac{1}{2} \left(\frac{1}{R_\infty} - R_\infty \right) \Big|$$

we find

$$\frac{K}{S} = \frac{(R_{\infty} - 1)^2}{2 R_{\infty}} \quad (2)$$

$$S X = \frac{1}{b} \cdot \text{Arcotgh} \frac{1 - a \cdot R_0}{b \cdot R_0} \quad (3)$$

$$\frac{K + \Delta K}{S} - \frac{K}{S} = \frac{(R_{(K+\Delta K)\infty} - 1)^2}{2 R_{(K+\Delta K)\infty}} - \frac{(R_{\infty} - 1)^2}{2 R_{\infty}} \quad (4)$$

$$T = \frac{b}{a \cdot \sinh b S X + b \cosh b S X} \quad (5)$$

where R_0 = reflection in front of a black background, $(R_{K+\Delta K})$ = reflection with additional absorption, X = layer thickness, T = transmission.

Determination of the Absorption and Scattering Coefficients

The separate determination of S and K is the simplest when the material is available in sufficiently thin layers, for example, paper and similar materials. Even for paint production, it is extremely difficult to determine the layer thickness accurately.

The fact that the layer thickness can be eliminated using Equation (3) during the measurement of the reflection in front of the black and the white background is a great advantage. The layer thickness must be uniform and so thin that the reflection differences can be determined photometrically with sufficient accuracy.

It is usually difficult to introduce an additional but exact absorption, especially in the visible range. In the infrared, however, the absorption can be changed in a measurable

way by adding small amounts of water which can be determined gravimetrically and accurately. This makes it possible to determine K and S individually.

Finally S and K can be calculated separately from the intensity of the light passing through the layer [see Equation (5)]. The graphical representation of Judd [9] (see Figure 10) is well-suited for the separate determination of K and S within certain reflection range limits. This representation contains two families of curves with R_{∞} and $S \cdot X$ as parameters in a field with R_0 and the Tappi contrast as ordinates. The Tappi contrast is the reflection ratio for black background and Tappi background (brightness 89%). Since a simple computation procedure can be used for backgrounds which do not deviate too much from the standard value. This form of representation is a very convenient method of determining the individual values of K and S if the layer thickness is known.

As an example, Table 2 shows the scattering coefficients for a normal piece of tracing paper as a function of wavelength between 0.4 to 2 μ . The decrease in the scattering coefficient as a function of wavelength could be expected. The data were determined with an elrepho Zeiss photometer in the visible range. In the infrared, the same instrument was used together with the 45° attachment. The Judd diagram shown in Figure 10 was used for the evaluation. However, values of the scattering coefficient /60 were obtained from the absorption changes due to humidity increases which were smaller than those given above by about a factor of 2. The reason for this deviation has not been fully explained.

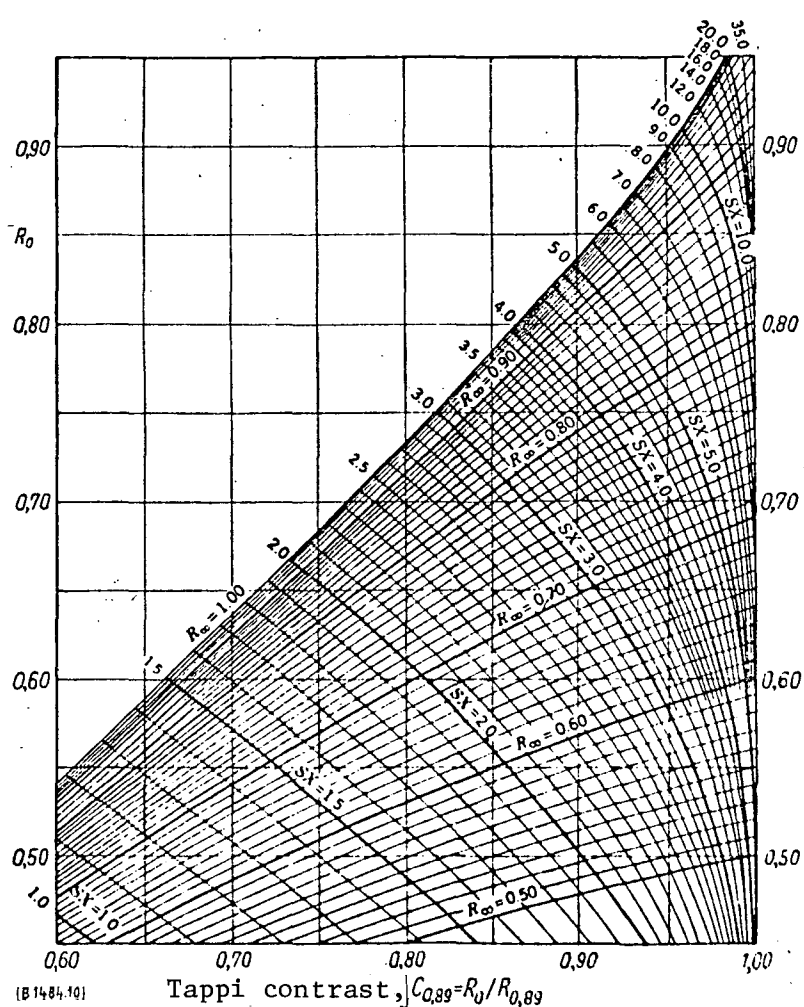


Figure 10. Judd-Tappi diagram for scattering coefficients times layer thickness as a function of contrast and R_0 .

TABLE 2. SCATTERING COEFFICIENT S OF 65μ , 58 g/m^2 TRACING TYPING PAPER DETERMINED FROM REFLECTION MEASUREMENTS WITH VARIOUS LAYER THICKNESSES X AS A FUNCTION OF THE WAVELENGTH USING THE JUDD-TAPPI DIAGRAM (Figure 10).

$\lambda [\mu]$	0.45	0.55	0.65	1.5	1.7	2.0
$S \cdot X$	1.83	1.70	1.55	1.34	1.17	1.03
$S [\text{cm}^2/\text{g}]$	315	293	267	214	202	181

TABLE 3. SCATTERING COEFFICIENT [cm^2/g] OF
VARIOUS MATERIALS CALCULATED FROM THE INFLUENCE
OF THE HUMIDITY CONTENT ON THE REFLECTION AT
 1.9μ .

Leather	141
Paper with filler	105
Paper (tracing)	79
Starch, powder form	54
Cotton	33
very fine weave	56
Wool	39 - 34
very fine	39
Artificial fertilizer	
(gray corn)	
granules	24
compressed	26

Table 3 shows the scattering coefficients for several products which were determined from Equation (3) and brought about by an absorption increase when the humidity was increased⁽²⁾. It can be seen that for the technically interesting products, the differences in the scattering coefficients are not especially large. Also, these values do not change noticeably when the grinding fineness is changed, provided that the products were sufficiently fine at the beginning.

⁽²⁾Because of the light scattering, the calculation must be done with twice the extinction coefficient, see Kubelka [8].

Penetration Depth and Layer Thickness

For layer thickness which are small with respect to the penetration depth, a small or a large part of the incoming light can no longer pass through without scattering and is therefore lost for the measurement. The scattering curves are then lower for a black background and the absorption bands are flattened. In general the penetration depth becomes smaller as the scattering coefficient is increased and the degree of reflection is decreased.

Using Equation (3) and for a ratio of $R_0:R_\infty = 0.95$ or 0.90 or 0.80 , respectively, the penetration depths were calculated as a function of R_∞ and are plotted in Figure 11. Therefore, for a reflection of 30 to 60%, the required layer thicknesses lie between S and $2 S$, where S can be taken from Table 3 for a number of products. According to this, sufficient reflection is already obtained for layer thicknesses between 100 to 200 μ . If a good reflector background is used (for example, shiny rollers), the layer thickness can be even smaller by a factor of 2 for running material or paper trajectories.

The optical humidity determination is only able to measure the humidity distribution inside the penetration depth of the radiation. The result is primarily influenced by the humidity of the upper layers inside of the penetration depth. In our method (drawing off water by heating the samples and moistening them in evacuated exsiccators with water in the bottom) the humidity distribution in the samples is mostly homogeneous. Thus, for example, it does not matter whether the reflection curves are determined in the sealed cuvettes just after the treatment or after long waiting periods.

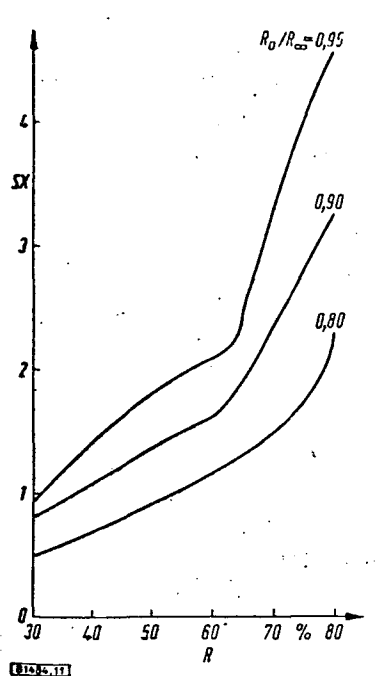


Figure 11. Relationship between penetration depth and scattering coefficients.

Transmission Curves in the Near Infrared

The scattering and absorption coefficients can best be determined from the transmission of the sample material using transparent layers in the wavelength range of interest which extends from 0.7 to 2.5 μ . Then, according to Equation (2) the scattering coefficient S can immediately be obtained if K and R_∞ are known. Then the influence of the water absorption can be determined directly from the Kubelka-Munk curves or the corresponding tables, for

example those of Judd [9]. Unfortunately the absorption values in the near infrared are only known for a few products and only for products which can be made into thin transparent layers or which are available in the liquid phase. For example, the transmission curve of sugar can be obtained from the melt, but there still remain some differences between the absorption of the crystalline sugar and that of the molten sugar.

Presentation of the Results

The numerous reflection spectra recorded in connection with the humidity determination can be simply presented in two ways.

Kubelka-Munk Diagram

The absorption in the water bands can be plotted using so-called Kubelka-Munk ordinates. For this purpose, tracing sheets are prepared which have as ordinates the degrees of reflection plotted in such a way that the corresponding K/S values are linear. The humidity content in percent of the dry weight is used as the abscissa. If the theory is valid and if perfect experimental results are available, the curves should be straight lines the inclinations of which are inversely proportional to the scattering coefficients of the products.

Figures 12 and 13 show the measurement results for various products. Except for scatter, the linearity conditions are quite well satisfied. One can observe the essential characteristic of the reflection curves which is that, for small additions of absorbing material, the reflection decreases very drastically. If the concentration is increased further, the reflection values change less and less.

For large humidity contents or for nonhygroscopic powders, the scattering coefficient of the products decreases because the cavities are filled with water. This behavior can also be found in several curves in the Kubelka-Munk diagram. They then bend in the upwards direction.

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Linear Quotient Representation

Usually the deviations caused by changes in the scattering coefficients can also be eliminated by plotting the ratio of the reflection values at 1.9μ and 1.7μ . This type of representation is also well-suited for the measurement procedure, because the reflection ratio $1.9 \mu:1.7 \mu$ is used as a characteristic quantity

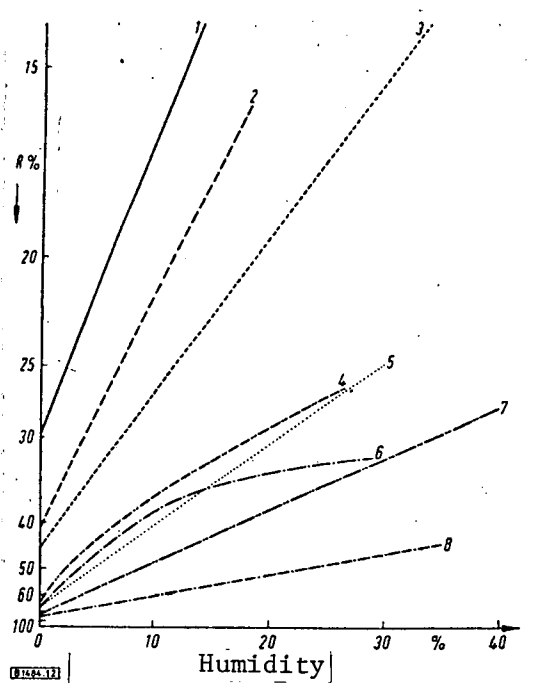


Figure 12. Reflection at 1.93μ on the Kubelka-Munk diagram.
 1 - methylcellulose; 2 - gelatine;
 3 - wool; 4 - cotton; 5 - starch;
 6 - flour; 7 - paper; 8 - leather.

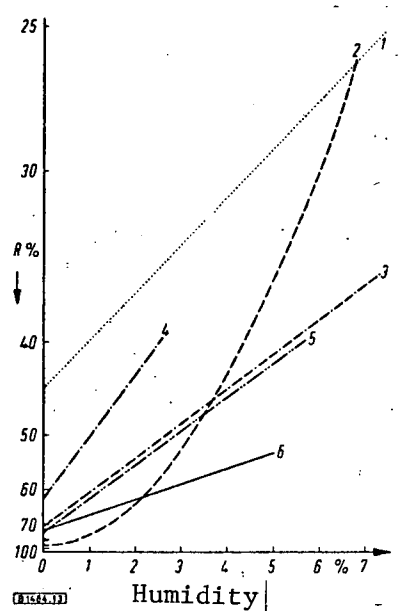


Figure 13. Reflection at 1.93μ using the Kubelka-Munk diagram.
 1 - fertilizer; 2 - sorbitic potassium;
 3 - Hostapon T; 4 - Benzidine yellow HG;
 5 - Hansa yellow 10 G; 6 - Mowital B 60 SL.

for the water content. In this way curves are obtained which first drop off sharply at low water contents and then become flatter for higher water contents. This is shown in Figures 14 and 15. Perturbations in the surface properties, packing density and changes in the scattering coefficients with the water content are then mostly eliminated. The plotted result is essentially a unique function of the humidity content of the product. The measurement is quite sensitive for small humidity contents. This is often important for technological purposes, for example when controlling drying installations so as to achieve the optimum efficiency.

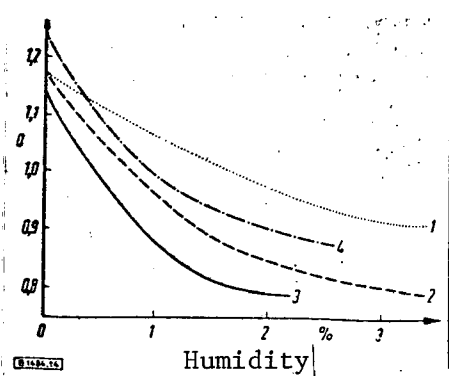


Figure 14. 1 - Mowital B 60 SL; 2 - Hansa yellow 10 G; 3 - Benzidine yellow HG; 4 - Hostapon T.

Reflection quotient $1.93 \mu / 1.70 \mu$ as a function of humidity.

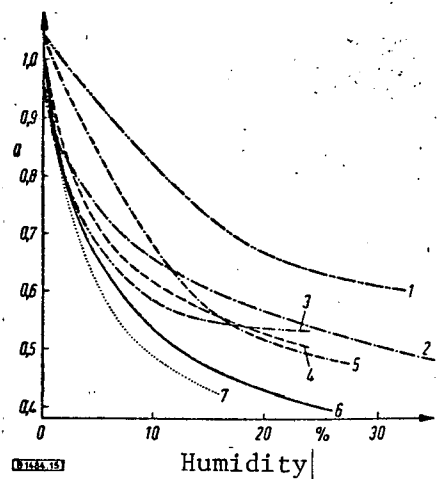


Figure 15. 1 - Leather; 2 - paper; 3 - flour; 4 - cotton; 5 - starch; 6 - wool; 7 - gelatin.

Reflection quotient $1.93 \mu / 1.70 \mu$ as a function of humidity.

Influence of the Particle Size

The scattering coefficient also depends on the particle size. However, this dependence is no longer important if the material is initially sufficiently finely dispersed, i.e., if the primary particles have a size on the order of a few hundredths of a millimeter.

Influence of the Basic Absorption

The range of application for optical humidity measurements is also limited because the degree of reflection of the sample cannot be lower than a certain amount because then the useful light yield is too small. Also, the influences of the water absorption continues to become smaller.

It appears that optical humidity measurements are completely impossible for products which do not reflect at all in the infrared. These are the materials whose absorption is based on electron conductivity, such as for example metal powder, coal, graphite, black iron oxide, generally inorganic pigments which are black in the visible range as well.

Final Remarks

It is obvious that a large number of additional influences of external parameters on the measurement results must be determined more accurately and taken into account as was done here in order to take complete advantage of this method. The ranges within which the optical humidity measurement is advantageous will then be determined as well as the ranges within which conventional methods will continue to be superior. However it can be stated that the instruments associated with this method are relatively simple and operate with very few disturbances. The final result is a specific indication of the water content of the samples. Also the fact that this humidity measurement method does not require contact and can operate continuously will be especially important in practice. Thus, for example, the humidity of coloring agent powders, granules and textiles after passing through textile driers is already being determined using the optical measurement method. The results are then used to control the drying process. /62

Finally we would like to point out that the reflection properties of matter are important for many other scientific areas of investigation as well. Thus relationships for the particle size can be derived as well as more accurate statements regarding the state of formation of the absorbed water. The entire complex of surface coloring proceeds according to the same laws which

should be investigated further.

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